Aerodynamic Issues of Unmanned Air Vehicles Workshop

U.S. AIR FORCE

Aero-Structural Coupling and Sensitivity of a Joined-Wing SensorCraft

Lt Jennifer Schwartz (AFRL/AFIT)
Lt Col Robert Canfield (AFIT)
Dr Maxwell Blair (AFRL)

5 Nov 2002

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
26 JUL 2004	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Aero-Structural Coupling and Sensitivity of a Joined- Wing SensorCraft	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **AFRL/AFIT**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001685, EOARD-CSP-02-5078, Proceedings for Aerodynamic Issues of Unmanned Air vehicles (UAV)., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

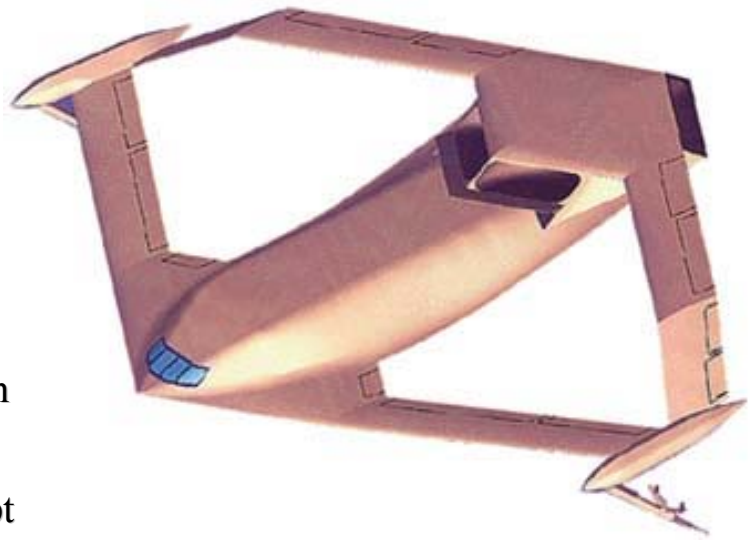
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**26**	

Overview

- Background on Joined-Wing SensorCraft
  - History of the Joined-Wing
  - SensorCraft Background
  - Configuration Issues
- Modeling
  - Parametric Modeling & Design Method
  - Aerodynamic Panel Model
    - PanAir
    - FlightLoads
  - Structural Finite Element Model
- Related Studies
- Conclusion

History of Joined Wings

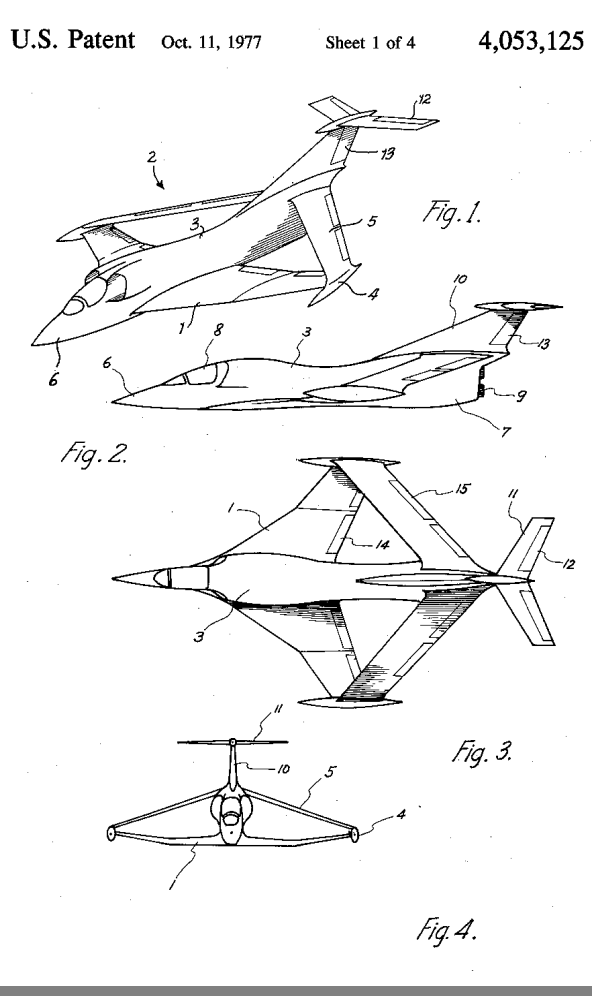
- Advantages Claimed
  - Reduce induced drag
  - Improve Stability
  - Strengthen Wing
  - Prevent Flutter



Lockheed Martin

"New Strategic Aircraft" Concept

Staggered Wing,
Ratony, 1977



Joined / Box Wing Studies

- **Wolkovitch (1986)**
  - Highly Integrated Structures & Aerodynamics Concept
- **Gallman & Kroo (1996)**
  - Buckling Critical
- **Livne (2001)**
  - Survey
  - Complex Aeroelastic Behavior

NASA : Box Wing Airliner (325 Passenger)

Lockheed Martin Concept to Replace C-141 & KC-135

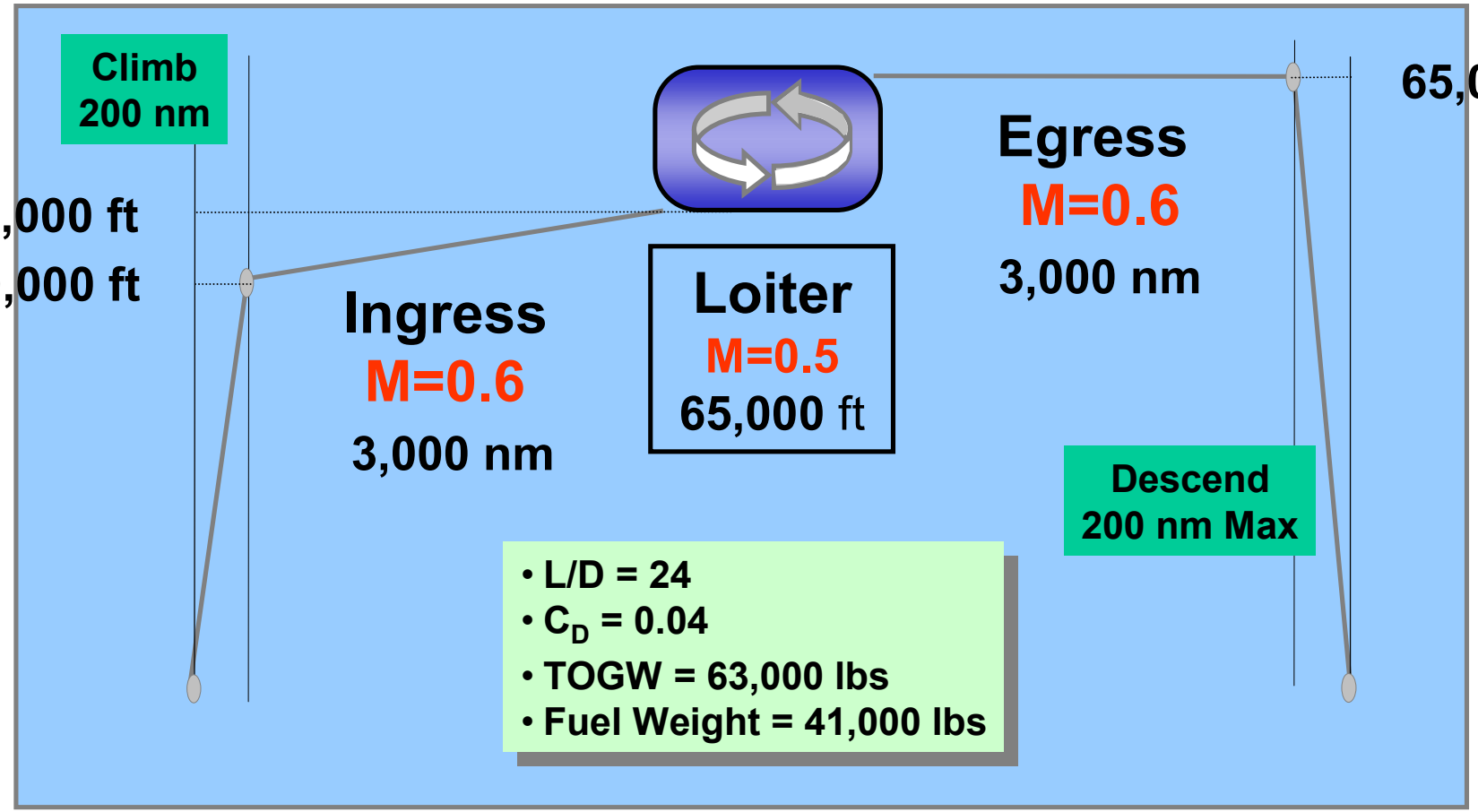
SensorCraft Background

- **Air Force Requirement**
  - **A UAV for continuous, long term intelligence, surveillance, and reconnaissance (ISR) missions**
  - **Joined wing magnifies sensor footprint by providing 360 degree coverage of the area of interest**

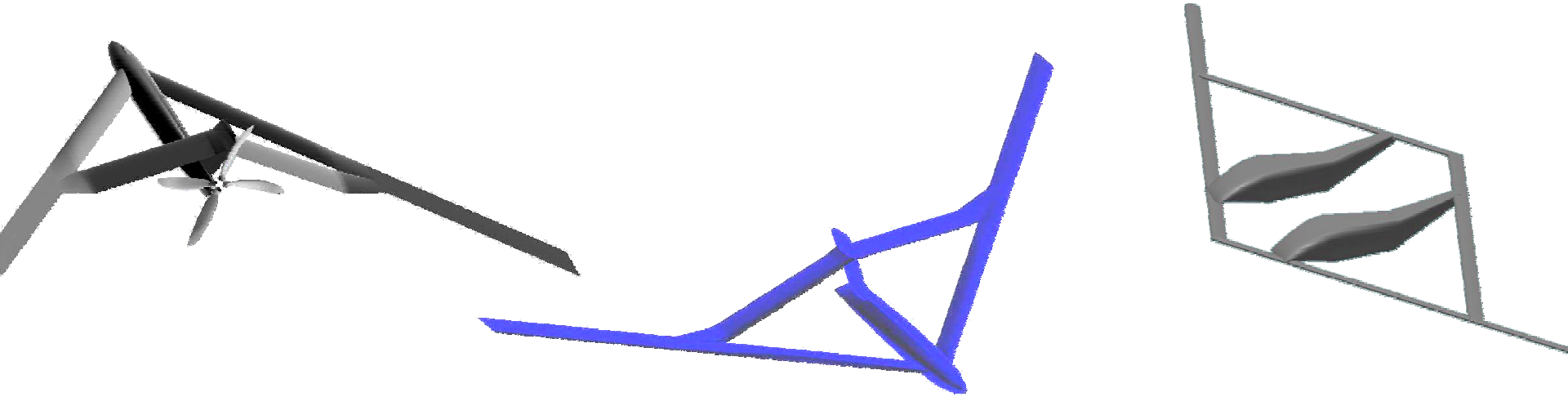
Notional UAV Joined Wing SensorCraft Concept (Boeing)

Notional Mission Profile

Breguet Range Equation: $$R = \left(\frac{V}{C}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W_{i-1}}{W_i}\right)$$



SensorCraft Concept



- Developed by a team of AFRL in-house engineers
- Designed with the concept of designing an aircraft around the desired sensor package, rather than trying to pack sensors into an already existing platform
- Provides the required 360 deg coverage in a joined-wing configuration
- Further analysis is now being performed by students at the Air Force Institute of Technology

SensorCraft Complexity

- **SensorCraft Issues**
  - Many current tools are unable to process unusual configurations
  - Need to examine several points in the mission profile
  - Complex aerodynamics at the joints
  - Conformal, load bearing antenna integration
  - Non-linear structural analysis
    - Wing buckling and bending
  - Interaction of structural and aero loads
- **Solution requires simultaneous, interactive examination of:**
  - Sensors, including the structural characteristics
  - Structural analysis
  - Flexible aerodynamic loads

Overview – Modeling

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Design Tools

AML Design Environment:

- Object-oriented With Native Geometric Modeling
- Dependency-tracking & Demand Driven Process
- Run-time Object Creation

PanAir Aerodynamic Solver:

- Linear panel geometry for complex configurations
- High order continuous singularity distribution
- Wake shaping capability

MSC.FlightLoads Solver:

- Combined structural-aerodynamic model

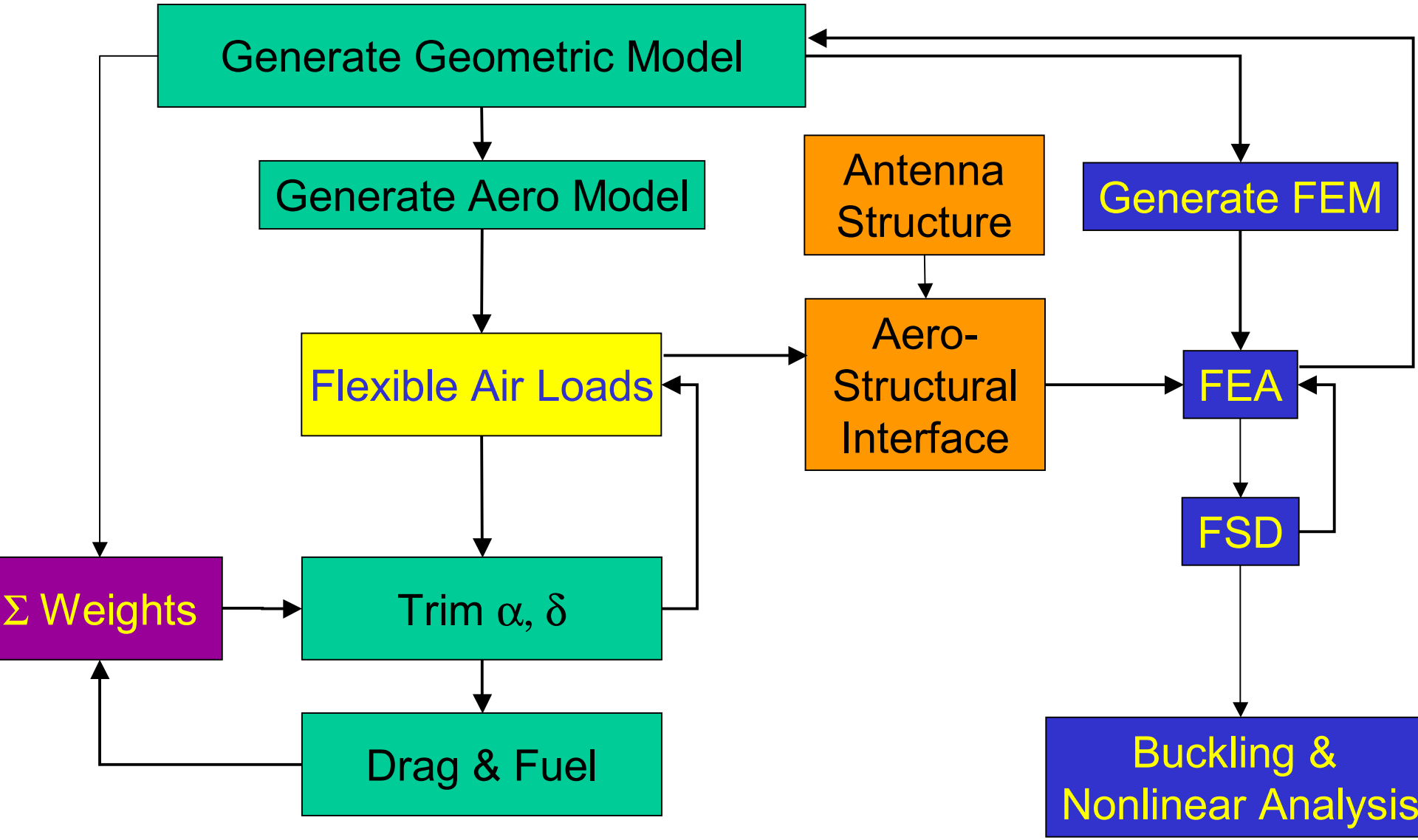
ASTROS:

- Structural Optimization
- Linear Fully-Stressed Design (FSD)

MSC.Nastran:

- Non-Linear Analysis
- Gradient-Based Buckling Design

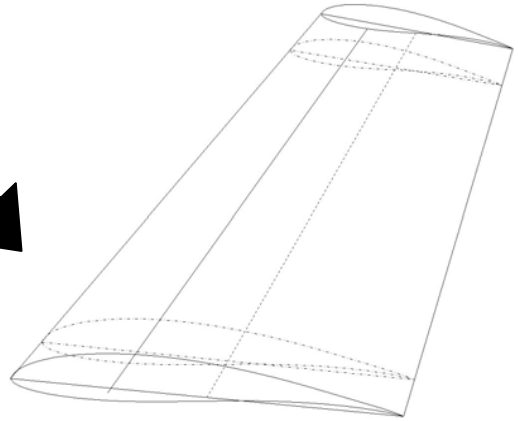
Joined-Wing Design Flowchart



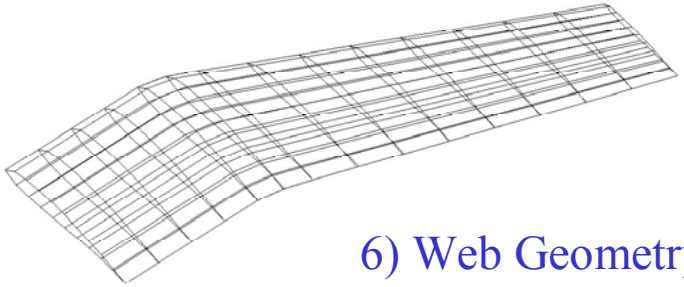
Object-Oriented Wing Building
~ AML Design Environment ~

Start with
Basic Building Blocks:
1) curve
2) contour
3) surface

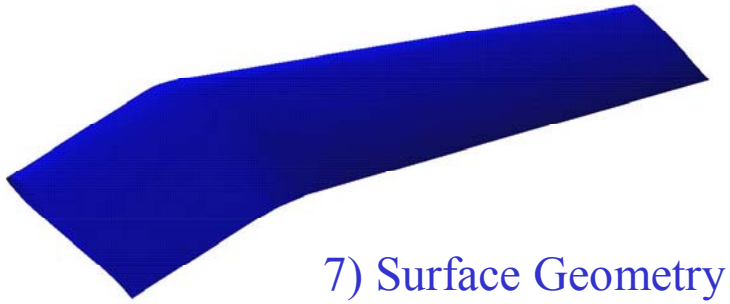
4) Airfoil



5) Wing Panel

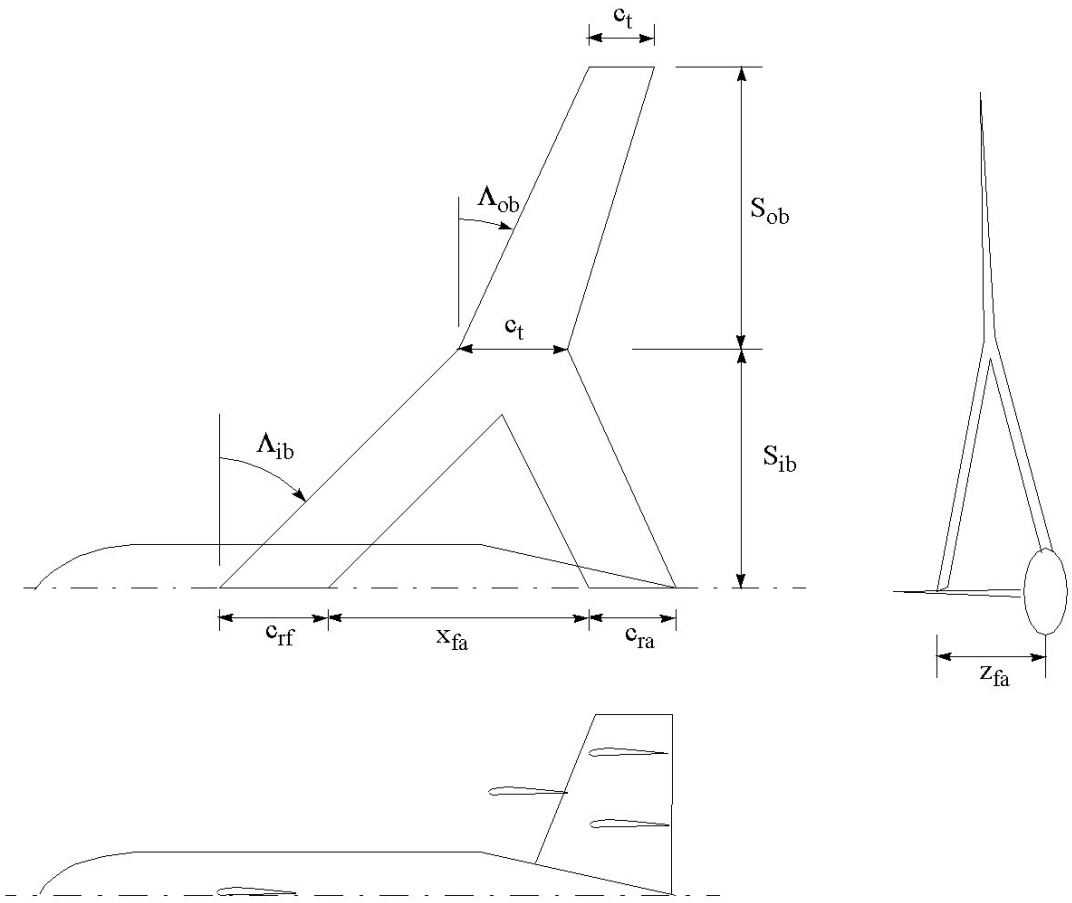


6) Web Geometry



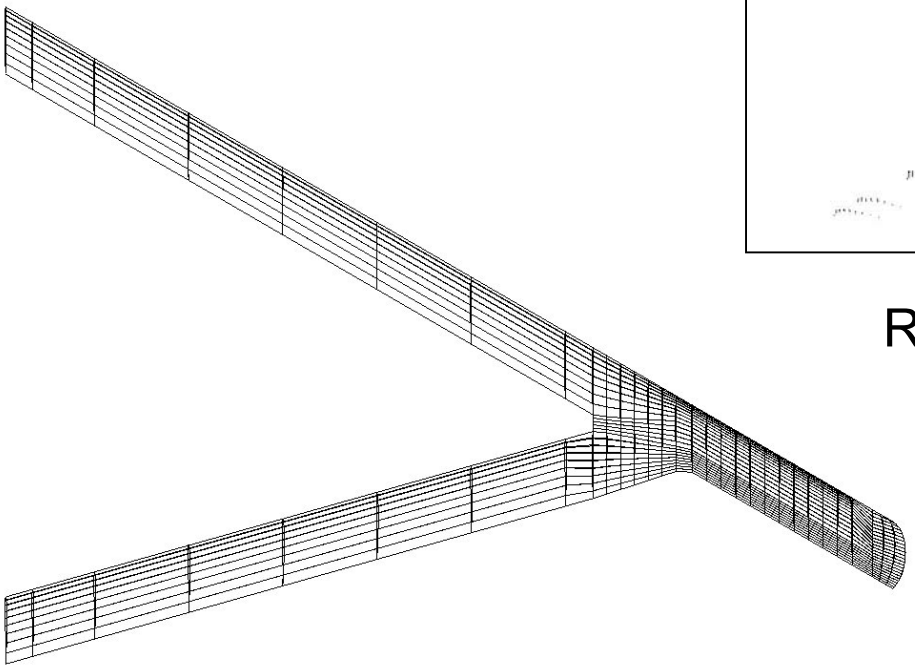
7) Surface Geometry

Fully Associative Parametric Variations
~ AML Design Environment ~

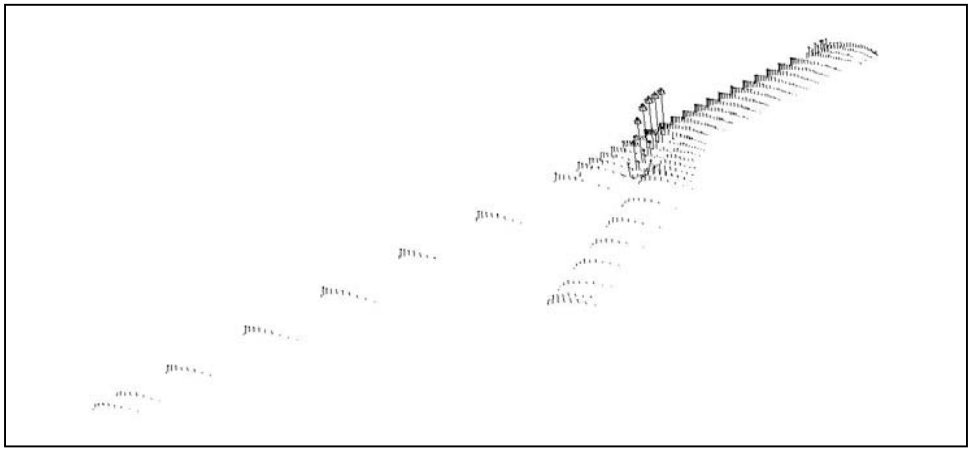


Inboard Span (S_{ib})	26.0 m
Outboard Span (S_{ob})	6.3 m
Chord (c_{rf}, c_{ra}, c_m, c_t)	2.5 m
Wing Separation (x_{fa})	22.0 m
Wing Offset (z_{fa})	7.0 m
Sweep (Λ_{ib}, Λ_{ob})	30 deg
Airfoil	FX-60-126-1
Planform Area	145.0 m^2
Wing Volume	52.2 m^3

Joined-Wing Aero Model
~ PanAir Aerodynamic Solver ~



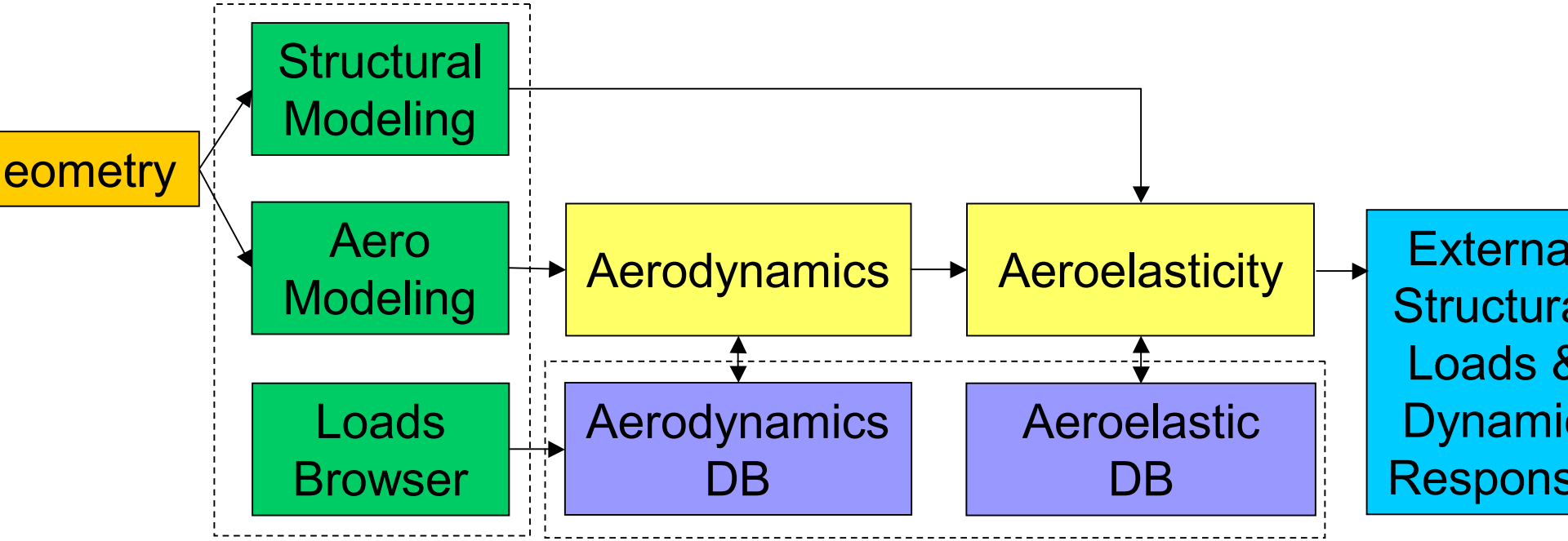
PanAir Panel Model



Rigid Trimmed PanAir Pressure Vectors on the Top Skin

MSC.FlightLoads Architecture

~ FlightLoads ~

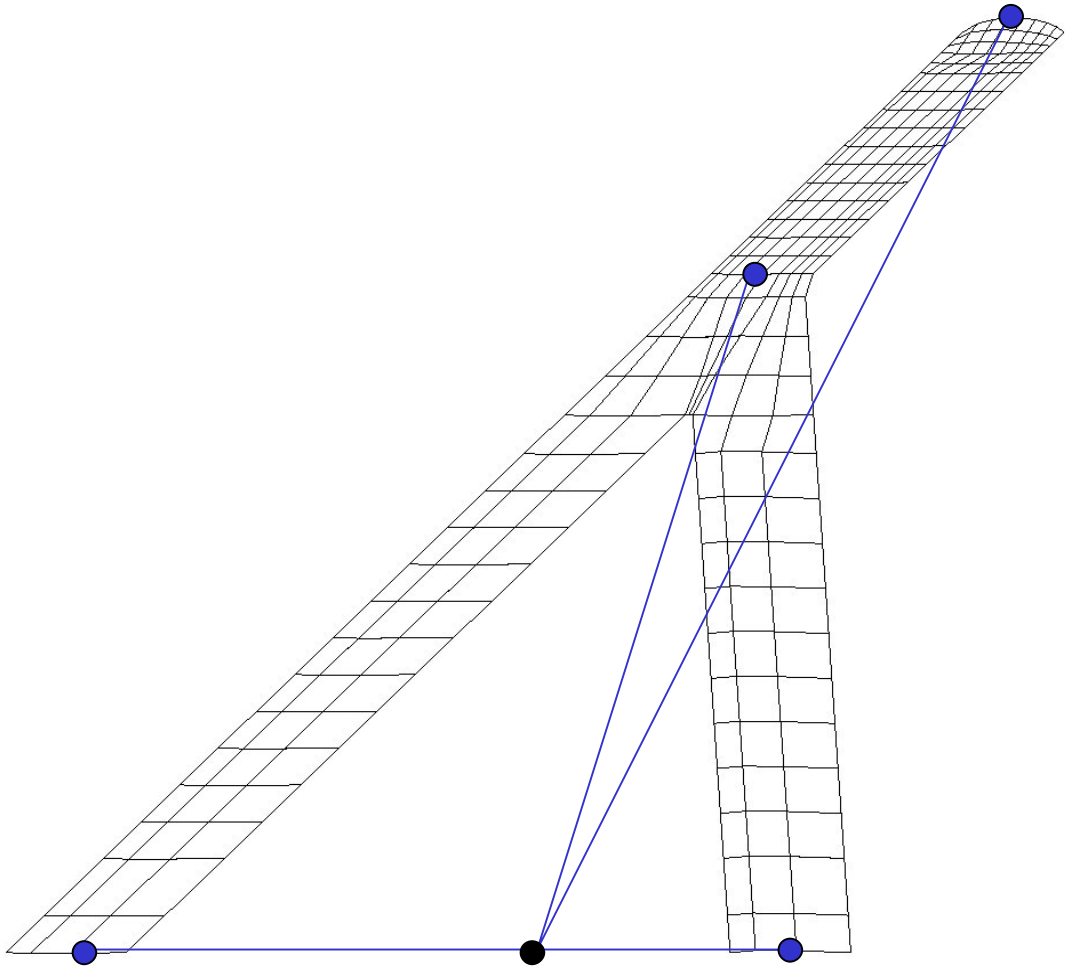


- Begin with geometry from user-preferred sources (i.e. IGES, CAD, etc)
- Define the aerodynamic and structural models
- Perform aerodynamic calculations
- Analyze the combined structural-aerodynamic model to provide both component and total vehicle aeroelastic responses
- View the results and produce external loads that can be passed to the stress group for detailed design and verification

Analysis Process
~ FlightLoads ~

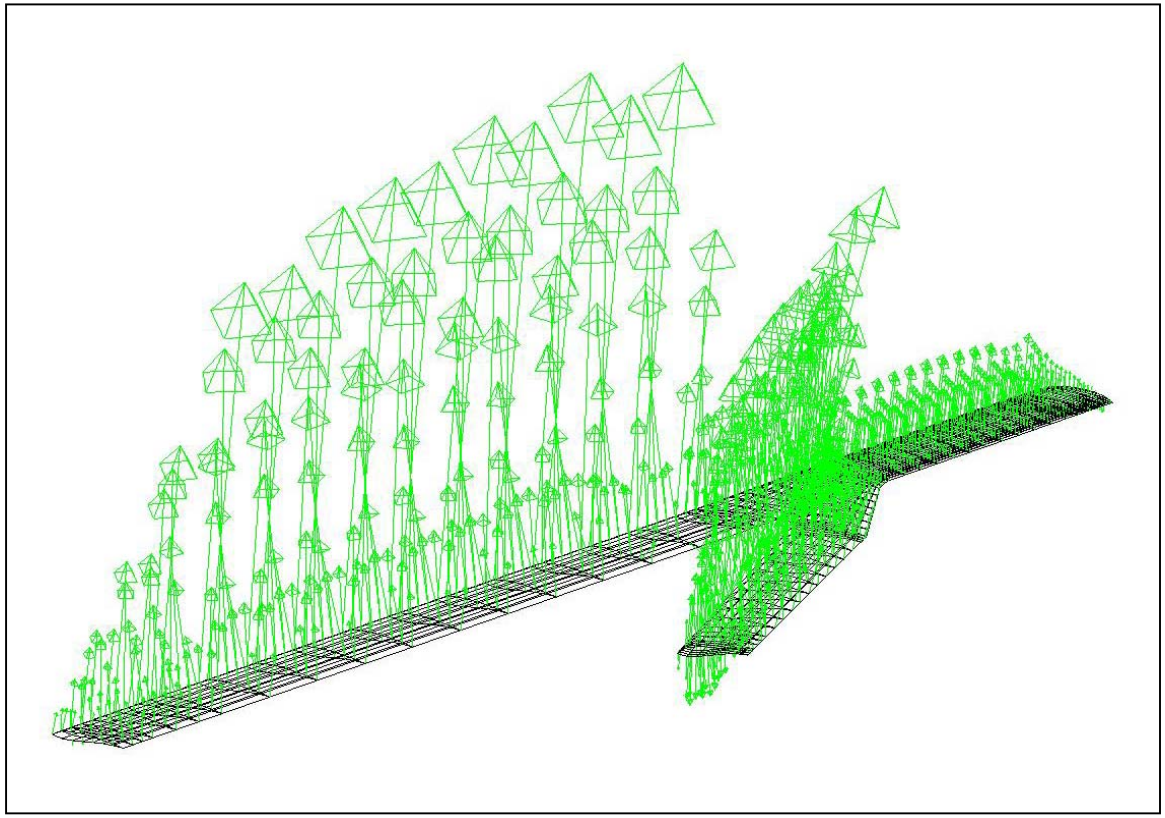
- **Input a simple structural geometry**
  - Include degrees of freedom
- **Build a flat-plate aero model, including control surfaces**
- **Spline the aero model to the structure**
  - Identify aero and structural monitoring points
- **Examine the model at various points in the mission profile**
  - Takeoff, ingress, mid-loiter, 2-g turn, egress, and landing
- **Export to NASTRAN for structural analysis**
- **Use NASTRAN results to complete the aerodynamic analysis**

Aero-Structural Model
~ FlightLoads ~



Joined-Wing FEM

Rigid Trimmed Forces at the Structural Grid Points



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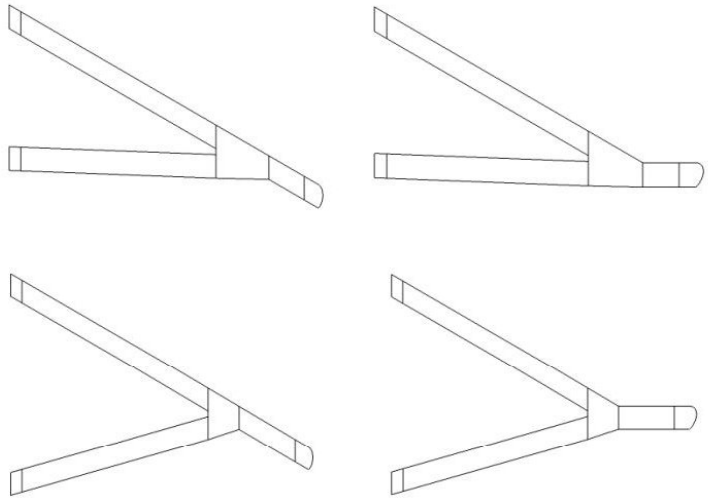
Related Research

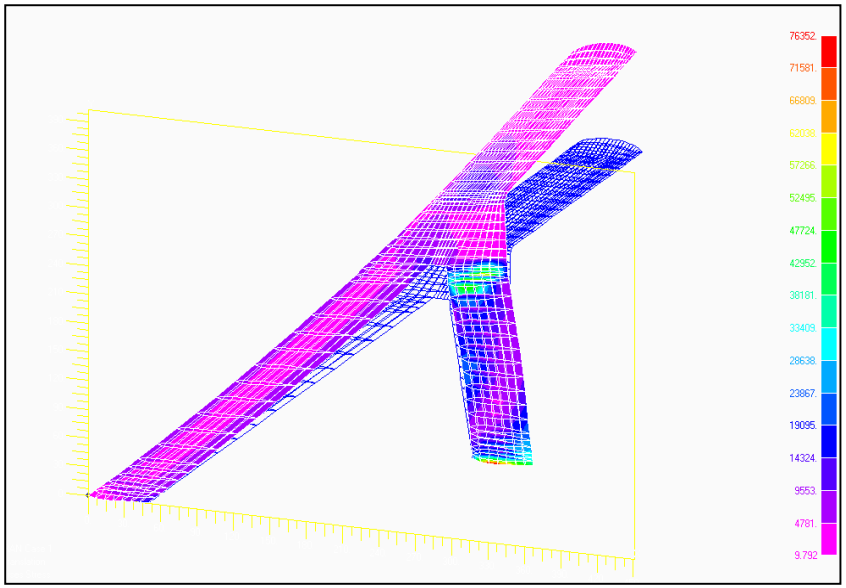
- **Previous Work**
  - Joined-Wing Structural Weight Modeling Study (Blair/Canfield)
- **Concurrent Work**
  - Stochastic Finite Element Analysis (Pettit/Ghanem)
  - Reliability Based Structural Design (Roberts)
  - Structurally Integrated Conformal Antennas (Smallwood)



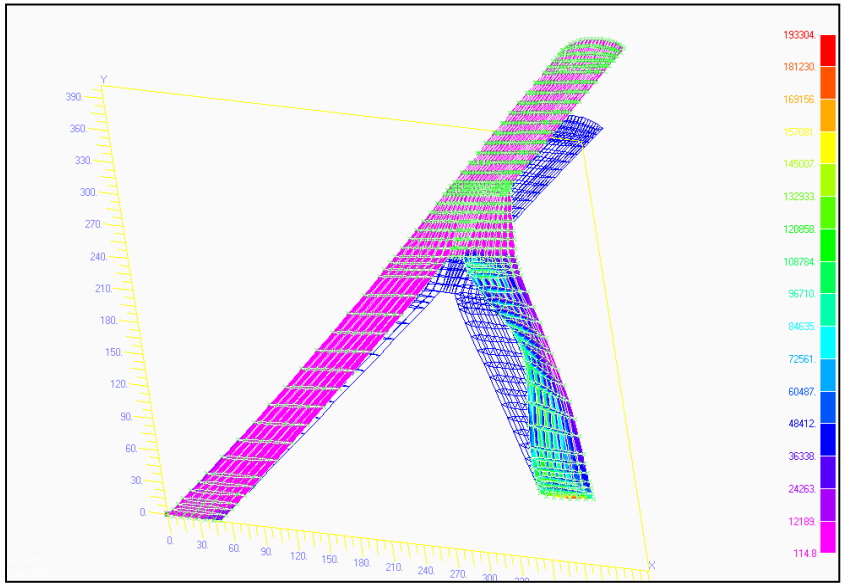
Joined-Wing FEM

~ Joined-Wing Structural Weight Modeling Study ~

- **FEM Resized (Fully-Stressed): Linear FEA**
- **Aeroelastic Load was Applied in Geometrically Nonlinear FEA**



***Linear* Results**

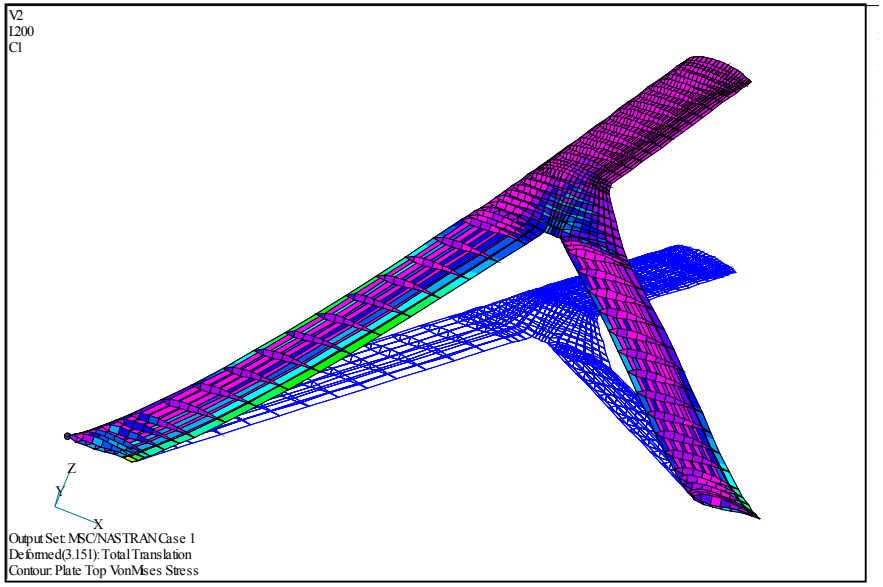


***Non-Linear* Results**

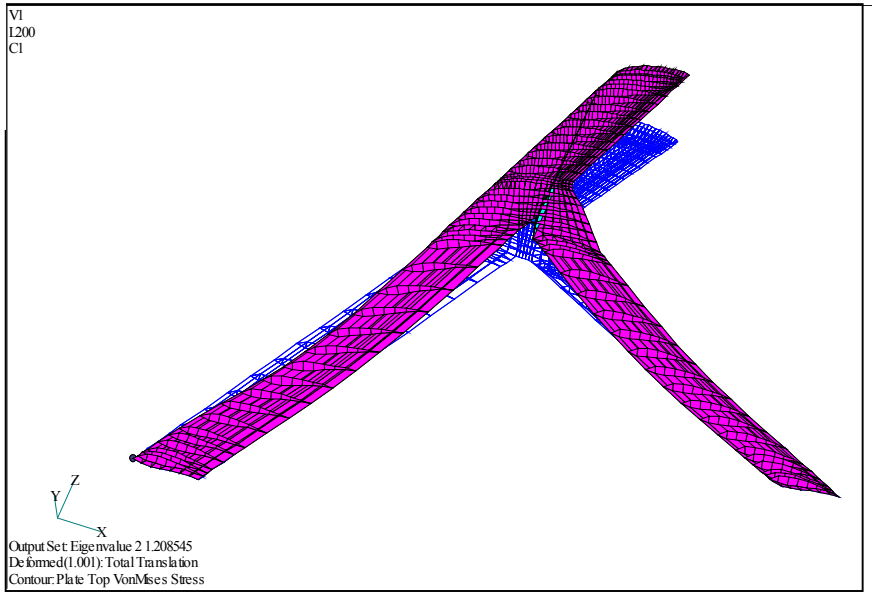
Conclusion: Non-linear Analysis Critical in Designing Joined-Wing

Linear FSD Flexible Loads Iter. 1

~ Joined-Wing Structural Weight Modeling Study ~



Linear FSD
Static Deformation



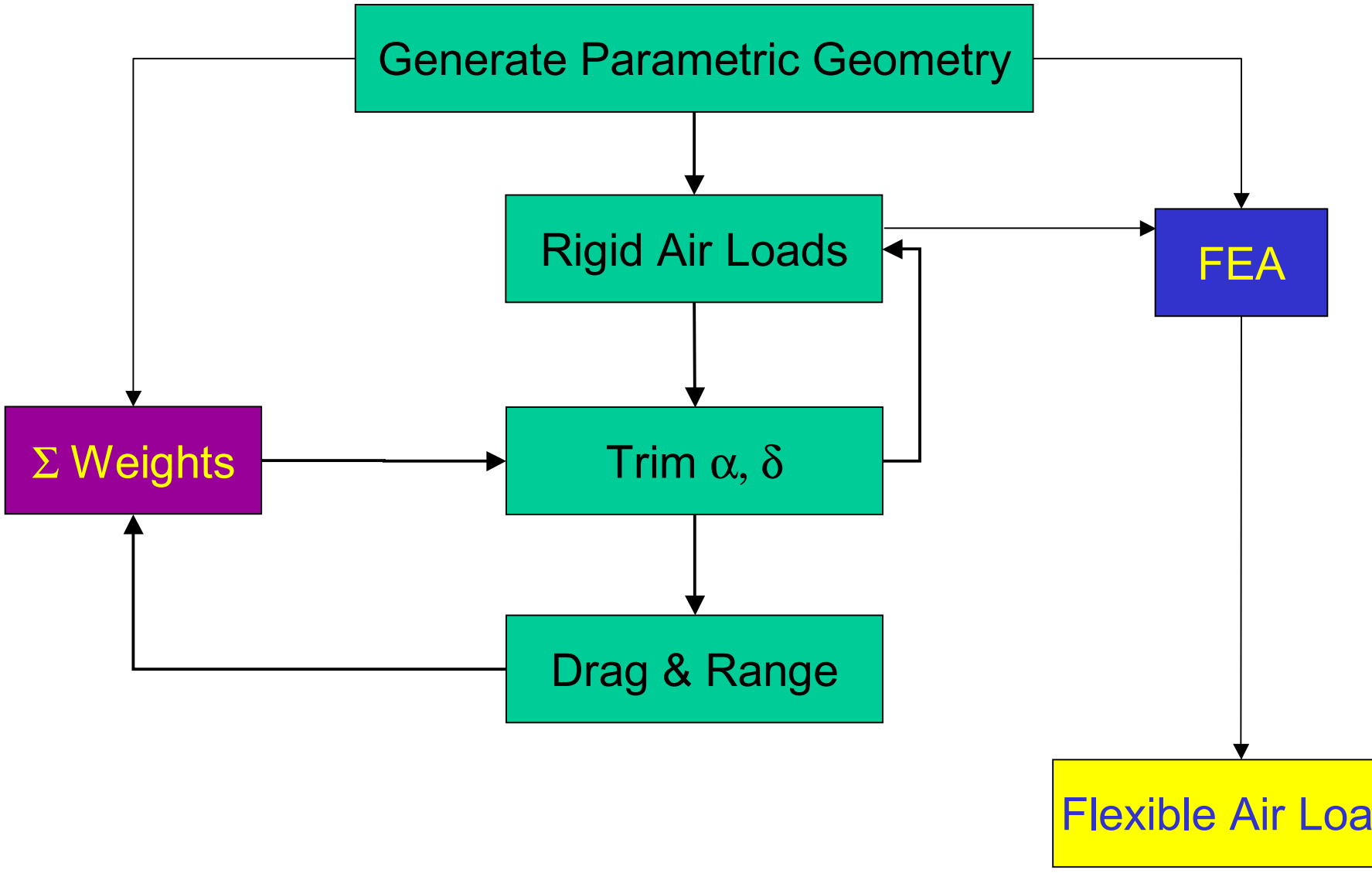
Buckling Deformation
of Linear FSD

Conclusions

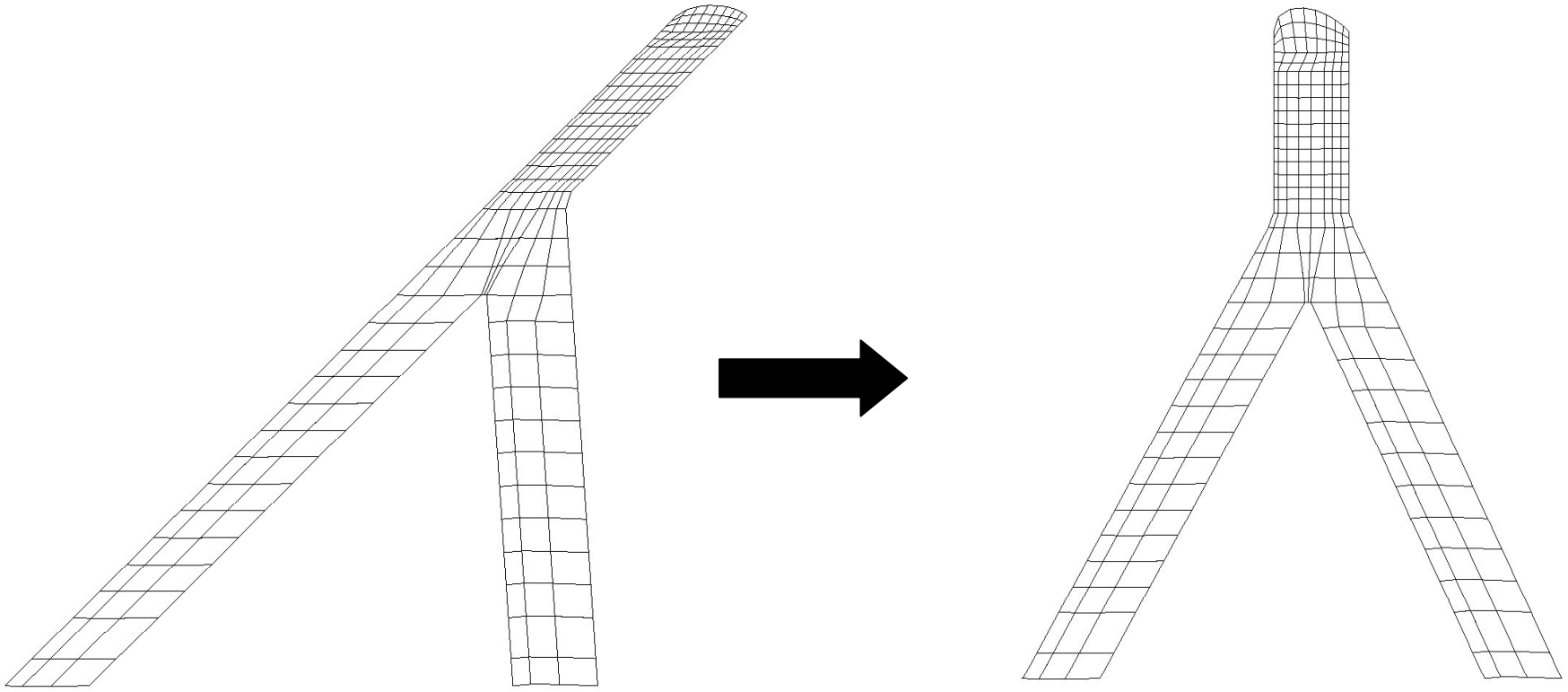
- **The joined-wing SensorCraft presents designers with unique technical issues**
- **Accomplishments**
  - Design Environment for Nonlinear Flexible Trim
  - Interactive Aero-Structural Model
- **Next Steps**
  - Un-Sweep Outboard or Aft Wing
  - Design for Buckling and Non-Linear FSD
  - Tailor Aft Wing Buckling to Alleviate Flexible Load
  - Verify aerodynamic results with CFD

Backup Slides

Joined-Wing Analysis Flowchart



Un-Sweep Outboard Wing



Negative Aft Wing Lift

Positive Lift